SIMULATION-AIDED PRODUCTION OF AIRCRAFT'S COMPOSITE PARTS

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ABSTRACT

Simulation has been successfully applied in many different areas such as manufacturing, service system, healthcare, transportation, supply chain, and etc. The opportunities to cut costs and to improve service levels in these sectors are tremendous by applying this technology. One of the largest application areas for simulation modelling is that of manufacturing systems, which has been applied for more than 40 years. This study is conducted at the local manufacturing plant that manufactures composite products for the aerospace industry. In this study, the simulation technique is applied to model the existing system to simulate the design and operational policies of the plant production process, which can be used to improve the performance of the different activities at the plant. The model focused on activities at the Secondary Manufacturing Area (SMA) of the aircraft's composite parts.

Key words: Simulation, performance, plant, production, aircraft

1.0 INTRODUCTION

Computer simulation is the discipline of designing a model of an actual or theoretical physical system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system (Banks *et al.*, 2000).

Simulation has been successfully applied in many different areas such as manufacturing, service system, healthcare, transportation, supply chain, and etc. (Harrell and Tumay, 1994). The opportunities to cut costs and to improve service levels in these sectors are tremendous by applying this technology.

It has become the main agenda of the manufacturing sector to produce cost effective products so as to stay competitive in business. In today's highly competitive marketplace, manufacturers use the latest technology to reduce time off production cycles, ramp up production and speed up time to market. One way companies can save time and cost is by using factory-simulation software, which tests the production line activity before it is implemented.

It is also normal practice by the management to conduct an experiment by setting the machines at certain speeds and record the system performance. However, this experimental approach of studying a manufacturing system may not be economically feasible (Grabau, *et al.*, 1997). It can be costly, time consuming and not productive. More over, it is difficult to comprehend and anticipate the reaction of the system to certain experimental conditions on the spot. However, many expensive errors can be avoided if simulation technology is used.

The design of new manufacturing systems or improving the existing system can be immensely supported by simulation as the designer is given an opportunity to assess the proposed system via properly designed experiments without the cost and time associated with physically building the system. A real-life system enviably contains randomness or variability and simulation is able to closely mimic these characteristics (Banks and Gibson, 1998; Thompson, 1994).

This study focuses on applying simulation technology to a manufacturing system in the aerospace industry in Malaysia. The aerospace sector is one of Malaysia's priority growth engines to achieve the national aspiration of being a developed nation by the year 2020 (British High Commission KL, 2002).

The manufacturing plant under study is a joint venture between two Malaysian companies and two American companies. The plant involves the production of advanced composite materials for the aerospace industry. The plant produces fixed trailing edge parts for the wings of an aircraft.

2.0 SIMULATION IN THE MANUFACTURING INDUSTRY

Simulation has become an increasingly important operations research technique and one of the most powerful tools available to decision-makers responsible for the design and operation of complex processes and systems. Simulation has been applied to manufacturing problems for more than 40 years (Law and Kelton, 2000). It makes possible the study, analysis and evaluation of situations that would not be viable. In an increasingly competitive world, simulation has become an essential problem solving methodology for engineers, designers and managers. Simulation models of business processes can help overcome the inherent complexities of studying and analysing businesses, and therefore contribute to a higher level of understanding which can be used to improve processes (Harrell and Tumay, 1994).

In terms of the business environment, simulation models usually focus on the analysis of specific aspects of an organisation, such as manufacturing or finance. It is the act of reproducing the behaviour of a system using a model that describes the processes of the system. Simulation technology holds tremendous promise for reducing costs, improving quality, and shortening time-to-market for manufactured goods (McLean and Leong, 2001).

According to Kelton *et al.* (2002), the main reason for simulation's popularity is its ability to deal with very complicated models of correspondingly complicated systems. This makes it a versatile and powerful tool. Besides, the obvious reduction in cost of computers and simulation software, emergence of more user-friendly and powerful simulation software, increase in the speed of model building and delivery, and acceptance of an established set of guidelines of simulation model building (Ülgen and Williams, 2001), make simulation all the more attractive.

Manufacturing simulation focuses on modelling the behaviour of manufacturing organisations, processes, and systems. Simulation models are built to support decisions regarding investment in new technology, expansion of production capabilities, modelling of supplier relationships, materials management, human resources, and so forth. Alternative proposed system designs or alternative operating policies can be compared via simulation to see which best meets a specified requirement.

Recent illustrative uses of simulation in the manufacturing industry are seen in the continuous improvement of processes for an aerospace manufacturer

(Adams *et al.*, 1999), implementation of moving line technology concept at Boeing factory (Lu and Sundaram, 2002), study on production capacity of Mercedes-Benz All Activity Vehicle (AAV) facility (Park *et al.*, 1998), prediction of system performance of an electro-phoretic deposition plant (Chan, 1995), and in business process re-engineering project (Irani *et al.*, 2000).

Miller and Pegden (2000) list a number of common manufacturing system features that are included in the simulation model when preparing to perform a manufacturing simulation study. The features are:

1. Resources, such as equipment, labour and material. The availability of resources is typically defined by shift patterns and/or the production rate, arrival or consumption of material.
2. Material handling devices, such as conveyors, automated guided vehicles (AGV) and lift trucks.
3. Control logic for managing the movement of a typical job from workstation to workstation.
4. Workstation logic, where the processing of work at a workstation typically involves multiple phases (e.g. setup, processing, teardown). Additionally, each phase may require a different set of resources. The logic may also include concurrent processing and transfer batching between workstations.
5. Buffers, where in many manufacturing systems, buffer space is limited and is a critical bottleneck in the system. A full output buffer can block the associated workstation and a full input buffer can block upstream workstation.
6. Orders/Process plans, where each part type may follow its own process plan through the facility.
7. Processing data, which is distributed between the process plan, workstation, and selected resource.
8. Reports, which include both facility metrics and job processing time, and cost data.

The following are some of performance measures commonly estimated by simulation in manufacturing (Law and McComas, 1998):

1. Throughput
2. Time in system for parts
3. Time parts spend in queues
4. Queue sizes
5. Timeliness of deliveries
6. Utilisation of equipment or personnel

3.0 SYSTEM DESCRIPTION

Figure 1 shows the general flow of production processes at the plant under study. The current production rate of the plant is 110 parts per day. The production floor is divided into two areas based on the plant layout i.e. Primary Manufacturing Area (PMA) and Secondary Manufacturing Area (SMA).

There are only two processes involved in PMA, which are ply cutting and ply layup. The production process begins when a production planner issues a shop p-copy (manufacturing plan), which describes the process routing. Once the p-copy is issued to the production line, the ply cutting process starts before the plies are laminated (ply layup process). The semi-finished product then flows through SMA which involves other processes such as cure, debag, trim, deburr, non-destructive testing (NDT), dimensional inspection, paint and final inspection. The study focuses on modelling of activities carried out at the SMA. At SMA, a batch of semi-finished products undergoes a curing process using an autoclave oven. Then a debag process is used to remove the bagging materials from these parts. The parts are then trimmed using a water jet machine controlled by a computer program. A deburr process is then used to smoothen the edge of the parts. A non-destructive testing process is then applied to scan any internal defect of the parts. The next process, called dimensional inspection, is used to examine the dimension of the parts. After completing these processes, the parts are then ready for painting. The final inspection is done manually to check the part quality and endorse the parts for packing and shipping.

4.0 GOALS OF STUDY

Simulation study at this plant was initiated because the workload for an existing system is predicted to change. The managers needed to understand the impact of such changes on system performance. The simulation model offers practical information to the management to make informed decision performance in these situations.

The main objective of the study is to model and simulate the design and operational policies of the production process, which can be used to improve the performance of the different activities at the factory. The study also intends to evaluate the performance of existing operations and capability of the plant resources. It can then be used to find an alternative design for an optimal

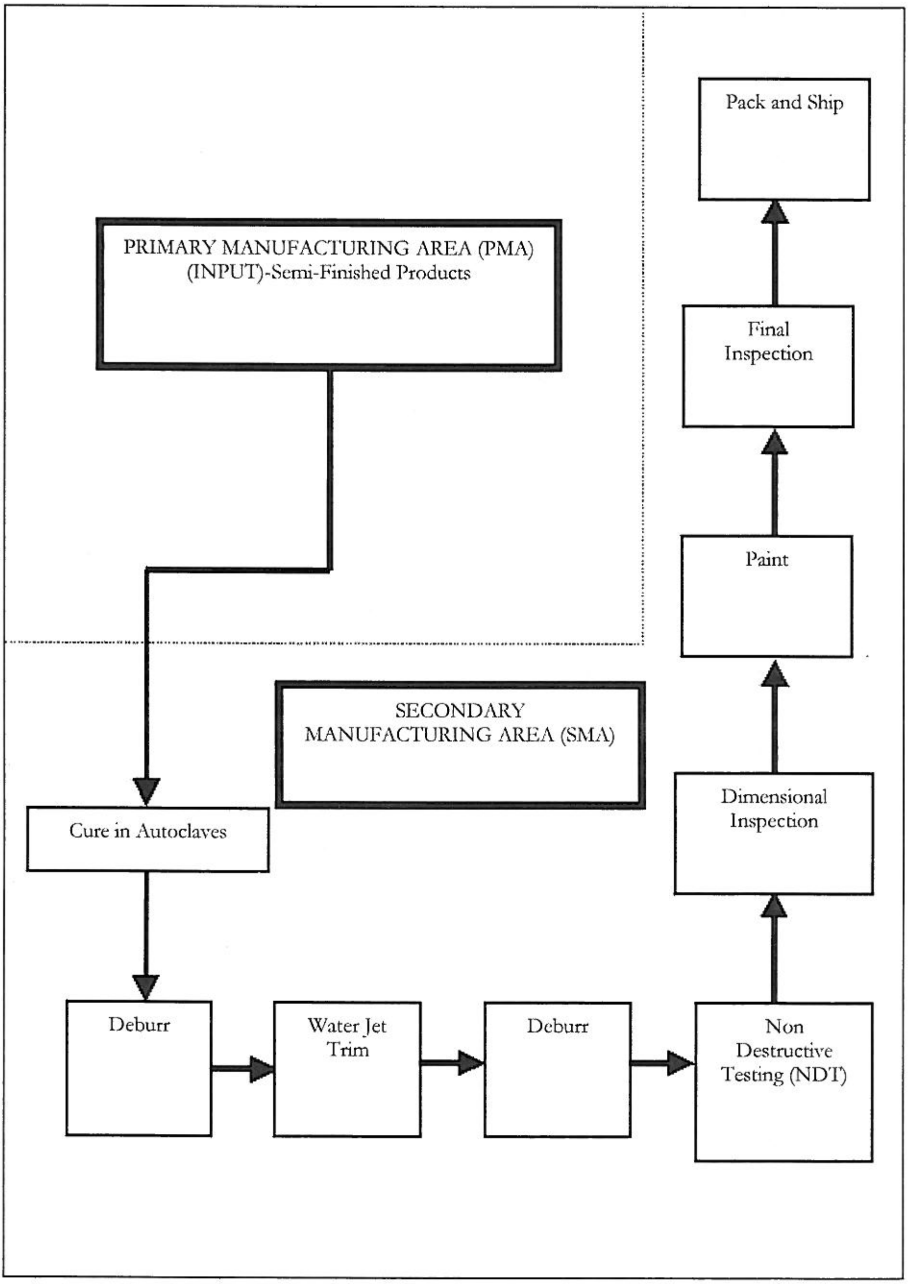


Fig. 1: Schematic of Production Flow

production system. The focused activity of the modelling study is of the operations at SMA with stochastic distribution of process time.

The study was to provide information on machine utilisation, part flow time, and information on bottlenecks. The simulation was also used to test "what if " scenarios such as increased production requirements, resources utilisation and other effects of operating variables on production.

5.0 MODEL DEVELOPMENT

The actual production process was studied and modelled into a computer simulation programme. In this paper, software was used to build the model. The model was then simulated and analysed to investigate several alternative designs.

Where a new manufacturing system or an existing system is to be modified, the computer simulation can be used to:

- identify potential problems, such as bottlenecks,
- investigate alternative plant layouts, and
- determine required equipment performance.

The first step of the project was to define and formulate the problem. Understanding the problem clearly will make the modelling task become much easier. The second step was the model development. The model development is the most visible part of the simulation study. The model development will adhere to the goals and objectives and will be completed in phases of increasing complexity. The model will first capture the basic logic of the system and the logic flow. Part movement and elements will be added and verified as the model is developed. As soon as basic model function has been encoded, more detail can be added for each location until the desired function is achieved. The last step was executing the experimentation and presenting the analysis results.

The software chosen for this case study was ARENA by Rockwell Software. It is a menu driven package and runs on an IBM compatible PC. The resulting layout was animated when the simulation was run, showing the movement of parts and resources with elapsed time. The simulation can be interrupted at any stage and a comprehensive reporting system can be viewed.

5.1 The Model Concept

Model building and analysis vis-à-vis simulation is an iterative process. A commonly recommended approach to simulation modelling is to start simple and then expand. In the planning phase, computer simulation can provide an operational assessment of the existing facility through the development of an "as-is" model. For this study ARENA simulation software was selected to construct the model. It is a general-purpose simulation package and is very powerful for many manufacturing applications (Kelton *et al.*, 2002). The Input Analyzer incorporated with ARENA allows the user to input raw data and fit a statistical distribution to the given data.

5.2 Input Data

Data analysis provides the driving force for any simulation model. Without input data, the simulation model itself is incapable of generating any data about the behaviour of the system it represents (Banks *et al.*, 2000). Input data were collected from the production plant and a comprehensive real life data on plant operation analyses was carried out.

The process times at eight SMA stations followed a certain distribution as shown in Table 1. The corresponding p-values for Chi-Square Test (C-S Test) and Kolmogorov-Smirnov Test (K-S Test), and Square Error value are also listed. The ARENA Input Analyzer automatically computed these values and chose the best distribution based on the minimum value of square error. For the curing process, the process time is deterministic and is set for four hours. Figure 2 (a-h) shows the generated histogram of distributed process times of the stations at SMA.

6.0 SIMULATION RESULTS

The statistics collected from the simulation model include parts throughput, parts flow times, utilisation of resources and work-in-process quantity (WIP). The simulation model was run for 5 replications and the average was recorded.

6.1 Parts Throughput

Throughput represents the number of parts for the period of one-week study.

Table 1: Distribution of Process Times

Process	Distribution	Expression	p-value (Chi-square Test)	p-value (Kolmogorov-Smirnov Test)	Sq-error
Debag	Triangular	TRIA(3.07, 3.52, 3.98)	>0.75	>0.15	0.002826
Water Jet Trim	Beta	4.9 + 1.04 * BETA(1.83, 2.38)	0.549	>0.15	0.006367
Deburr	Beta	15.1 + 4.75 * BETA(1.87, 2.11)	0.41	>0.15	0.011570
NDT	Normal	NORM(90, 0.784)	0.496	>0.15	0.005134
Dimensional Inspection	Weibull	10 + WEIB(5.27, 2.6)	0.607	>0.15	0.003868
Rework	Uniform	UNIF(40, 50)	>0.75	>0.15	0.009143
Paint	Beta	7 + 1.89 * BETA(1.86, 2.28)	0.387	>0.15	0.007036
Final Inspection	Triangular	TRIA(8.01, 8.49, 8.98)	0.0936	>0.15	0.026418

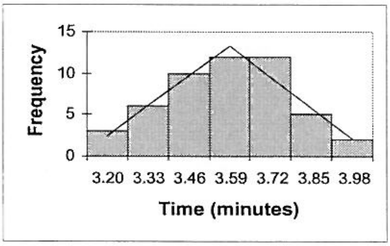
Table 3 shows the output of the throughput using simulation compared with the actual plant data and it seem that they are in good agreement.

6.2 Parts Flow Time

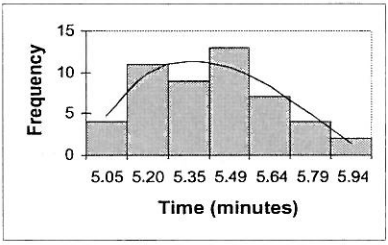
This is the time that a part spends in the system beginning at the cure process until final inspection. The flow time should be kept to a minimum to reduce work-in-process inventories, which carry hidden cost. The average parts flow time is validated with the actual data as shown in Table 4. The extreme value of this difference is 4.99%.

6.3 Resource Utilisation

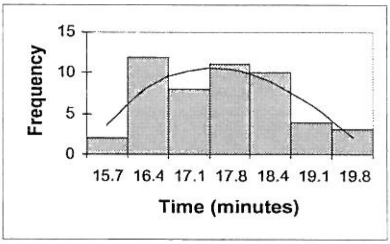
Resource utilisation is the ratio of the average resource number "busy" to the average resource number "scheduled". Resource utilisation is a common indicator of measuring how busy the machines and operators are. Table 5 exhibits the average of five replications scheduled utilisation for all resources. The output data indicate that the resource utilisations range from 81% to 98%. The utilisation is based on the actual working time excluding the time for breaks.



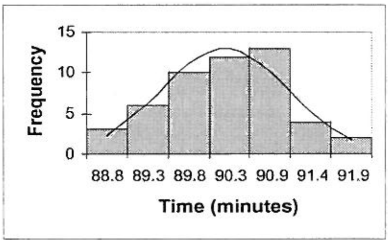
(a) Debag



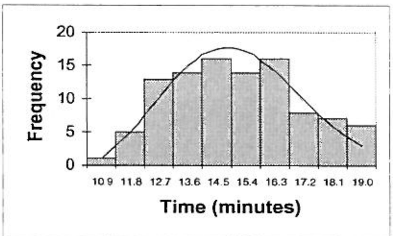
(b) Waterjet



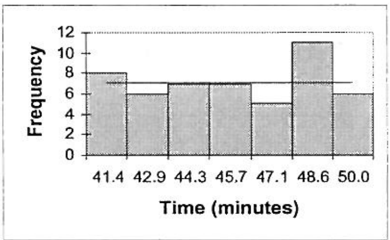
(c) Deburr



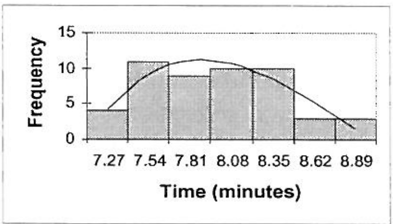
(d) NDT



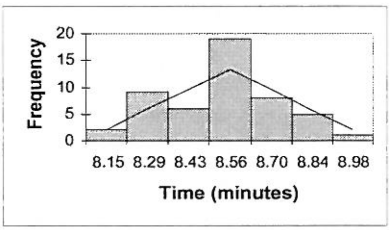
(e) Dimensional Inspection



(f) Rework



(g) Paint



(h) Final Inspection

Fig. 2 (a-h): Histogram of Process Time Distributions at Eight SMA Stations

Table 3: Number of Predicted Parts Compared with Historical Data

Part Type	Average Simulation	Historical Data	% Difference
Product I	96.8	99.4	2.62
Product II	117.8	118.8	0.84
Product III	115	118.8	3.20
Product IV	96.2	99.4	3.22

Table 4: Flow Time of Parts

Part Type	Average Simulation (hr)	Actual Data (hr)	% Difference
Product I	16.6421	17.0	2.11
Product II	16.6275	17.5	4.99
Product III	16.6642	17.5	4.78
Product IV	16.7610	17.0	1.41

Table 5: Scheduled Utilisation Values for Resources

Resource	Average
SMA	
Deburr Operator	0.98
Dimensional Inspector	0.86
Inspector 1	0.98
Inspector 2	0.97
NDT Technician	0.98
Debag Operator	0.81
Painter 1	0.89
Painter 2	0.88
Rework Operator	0.85
Waterjet Machine	0.97

6.4 Work-In-Process (WIP)

The WIP, for each type of part, was also computed from the model. The output from the simulation model was then compared with the historical data. The results are shown in Table 6.

Table 6: WIP for Each Type of Parts

Part Type	Average Simulation
Product I	31.46
Product II	36.78
Product III	36.98
Product IV	30.93
Total	**136.15**
Actual Data	**140**
% Difference	**2.75**

7.0 MODEL EXPERIMENTATION

In line with the plan of the company to expand its business by producing more parts, an increase of 20% of production capacity was experimented. The number of daily arrival was increased from 110 parts to 132 parts to investigate whether the present resource capacity can tolerate. Also, two additional alternative scenarios were also experimented. One of the scenarios is an increase of water jet trim machine operation time by 2 hours (20% increase) and 1.5 extra hours (18.75% increase) for other resources. The other scenario is an increase of 2 extra hours for resources with high utilisation (>95%) i.e. deburr operators, final inspectors, NDT machine and waterjet machine, and 1.5 hours for other resources (painters, dimensional inspectors, rework operators, and debag operators).

The simulation model was run for 5 replications and the average was recorded for each of the scenarios.

7.1 Parts Throughput

Table 7 shows and explains that the present resource capacity (Scenario 1) was unable to cater the production increase. However, Scenario 2 and 3 seem to be in good agreement with the 20% expected increase of throughput.

7.2 Parts Flow Time

Parts flow time of the three scenarios is given in Table 8. Scenario 1 shows that the parts will spend about 46% extra time compared to Scenario 2, about 23% and Scenario 3 about 18%.

Table 7: Number of Predicted Parts Throughput

Production Throughput	Simulation Output	Scenario 1	Difference	Scenario 2	Difference	Scenario 3	Difference
Product I	96.8	103.6	7%	117.4	21%	117.2	21%
Product II	117.8	119.2	1%	140.0	19%	141.4	20%
Product III	115.0	120.2	5%	141.6	23%	140.0	22%
Product IV	96.2	· 99.8	4%	119.4	24%	118.2	23%
Total Throughput	425.8	442.8	4%	518.4	22%	516.8	21%

Table 8: Flow Time of Parts

Flow Time	Simulation Output	Scenario 1	Difference	Scenario 2	Difference	Scenario 3	Difference
Product I	16.6421	30.9305	46.20%	23.6082	29.51%	20.5148	18.88%
Product II	16.6275	31.2450	46.78%	23.4104	28.97%	20.4746	18.79%
Product III	16.6642	30.9940	46.23%	23.4327	28.88%	20.4971	18.70%
Product IV	16.7610	30.8959	45.75%	23.4346	28.48%	20.3635	17.69%

7.3 Resource Utilisation

Table 9 exhibits the resource utilisation for the three cases. Deburr operator, final inspector 2, NDT technician and waterjet machine seem to be fully utilised in Scenario 1. However, for the other two scenarios, resource utilisations in Scenario 2 are higher than in Scenario 3.

7.4 Work-In-Process (WIP)

Parts WIP of the three scenarios is given in Table 10. Scenario 1 shows that WIP value is much higher compared to other scenarios.

Table 9: Resources Utilisation Three Scenarios

Resource Utilisation	Simulation Output	Scenario 1	Scenario 2	Scenario 3
SMA				
Deburr Operator	0.98	1.00	1.00	0.95
Dimension Inspector	0.86	0.90	0.89	0.87
Inspector 1	0.98	1.00	1.00	0.95
Inspector 2	0.97	1.00	0.99	0.93
NDT Technician	0.98	1.00	0.99	0.97
Debag Operator	0.81	0.84	0.82	0.81
Painter 1	0.89	0.91	0.91	0.91
Painter 2	0.88	0.92	0.90	0.90
Rework Operator	0.85	0.83	0.86	0.75
Water Jet Machine	0.97	1.00	0.98	0.98

Table 10: WIP for Each of Scenario

Work-in-process (WIP)	Simulation Output	Scenario 1	Difference	Scenario 2	Difference	Scenario 3	Difference
Product I	31.46	60.43	47.94%	43.86	28.27%	39.51	20.37%
Product II	36.78	74.31	50.51%	51.67	28.82%	46.40	20.73%
Product III	36.98	73.75	49.85%	51.19	27.76%	46.91	21.18%
Product IV	30.93	62.59	50.58%	43.72	29.25%	39.71	22.11%
Total	136.15	271.07	49.77%	190.43	28.51%	172.53	21.08%

8.0 CONCLUSION

This paper presents the results of a case study, which involved the use of computer simulation technique for production planning process in the aerospace industry. The model built was used to investigate a variety of issues, for example to determine the impact of a proposed change, without affecting production. The model is also able to determine the plant capacity under various situations. This enhances the ability to manage the system, control its capacity, and make better decisions regarding its operation, which in turn improves the ability to deliver quality products to customers.

When the production rate was increased by 20% to investigate the current plant capacity, the current resources capacity was unable to tolerate this increment as experimented in Scenario 1. Obviously, the parts flow time and WIP increase tremendously with the 20% increase of parts demand. Scenario 2 deals with the 20% production rate increase with an increase of water jet trim machine operation time by 2 hours (20% increase) and 1.5 extra hours (18.75% increase) for other resources. However, the utilisation of deburr operators, final inspectors, NDT machine and waterjet machine were found to be very high.

The last experiment, Scenario 3 is an increase of 2 extra hours for resources with high utilisation (>95%) i.e. deburr operators, final inspectors, NDT machine and waterjet machine, and 1.5 hours for other resources (ply cutters, layup operators, painters, dimensional inspectors, rework operator, and debag operator). Clearly from the simulation outputs, the result is the best design to meet the expected production throughput with acceptable resources utilisation.

The research and the simulation model developed have improved understanding of the inter-relationship of several physical components of the plant. The process of constructing the simulation models and reviewing the interaction of these components has given an insight into the different operational characteristics of the plant. The approach of system analysis is not only beneficial to the modeller, but it is also useful to the planner since it gives a thorough understanding on how the plant behaves and not how one thinks it behaves.

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